Advanced threshold voltage extraction methodologies for GaN High Electron Mobility Transistors

Loukas Chevas[1], Nikolaos Makris[1,2], Maria Kayambaki[2], Athanasios Kostopoulos[2,3], Antonios Stavrinidis[2], Errikos Lourandakis[4], George Konstantinidis[2] and Matthias Bucher[1]

[1]Technical University of Crete, School of Electrical & Computer Engineering, Chania, Greece
[2]Foundation for Research & Technology-Hellas, Inst. Electronic Structure & Laser, Heraklion, Greece
[3]Hellenic Mediterranean University, Dept. of Electrical & Computer Engineering, Heraklion, Greece
[4]Circuits Integrated, Athens, Greece

lchevas@tuc.gr / aek@physics.uoc.gr / mbucher@tuc.gr

As GaN High Electron Mobility Transistors (HEMTs) find more applications in RF and analog IC design, methods for their characterization need to be either invented or adapted from previously gathered expertise. In this work a methodology for the extraction of the Threshold Voltage parameter, initially developed for MOSFET devices is shown to be applicable to HEMTs as well. The device used for this end is a wide-long (W=250um, L=3um) AlGaN/GaN HEMT fabricated by IESL-FORTH, measured at temperatures ranging from -30°C, up to 110°C at the Electronics Laboratory at TUC using an HP 4142B Modular DC SMU and a probe station with a Temptronic TPO3000 temperature-controlled chuck.

The V_{TH} extraction methodology used in this work is continuously applicable to the whole spectrum of Drain biases and can be summarized as follows. The transconductance to current ratio for all regions of operation is given by: $\frac{G_m \cdot U_T}{I_D} = \frac{1}{n \cdot (1+q_s+q_d)}$, n being the subthreshold slope factor and U_T the thermal voltage. Using the charge-voltage relationship[2], V_P-V_X=$U_T[2q_x+\ln(q_x)]$, the pinch-off voltage $V_p=(V_G-V_{TH})/n$ can be calculated for an arbitrary point x along the channel as a function of the mobile charge density at x, q_x. Rearranging and solving for q_x, $q_x=0.5W_0[2e^{(V_P-V_X)/U_T}]$, W_0 being the Lambert-W function, and returning to the G_m/I_D formula, under the threshold condition $V_P=V_S$, a singular point on the G_m/I_D curve can be calculated [3], which corresponds to the threshold voltage, V_{TH}.

$$Z \overset{\text{def}}{=} \frac{G_m \cdot U_T}{I_D} \cdot n = \frac{1}{1.4263 + 0.5W_0(2e^{-V_{DS}/U_T})}$$

Fig.1b demonstrates the ease of application of the methodology to experimental G_mU_T/I_D vs. V_{GS} data, produced for all temperatures from the measured transfer characteristics I_D vs. V_{GS} such as those shown in Fig.1a (T=30°C).

In order to verify the applicability of this methodology to HEMT devices, the extraction was carried out as described and compared to an industry standard, the charge-based Adjusted Constant Current (ACC)[4] technique. The resulting plots of V_{TH} versus temperature (Fig.2a) and versus V_{DS} (Fig.2b) show a maximum deviation of 30mV between the two methods, over the whole temperature and V_{DS} bias range, with the G_m/I_D method producing both qualitative and quantitative results similar to the ACC method.

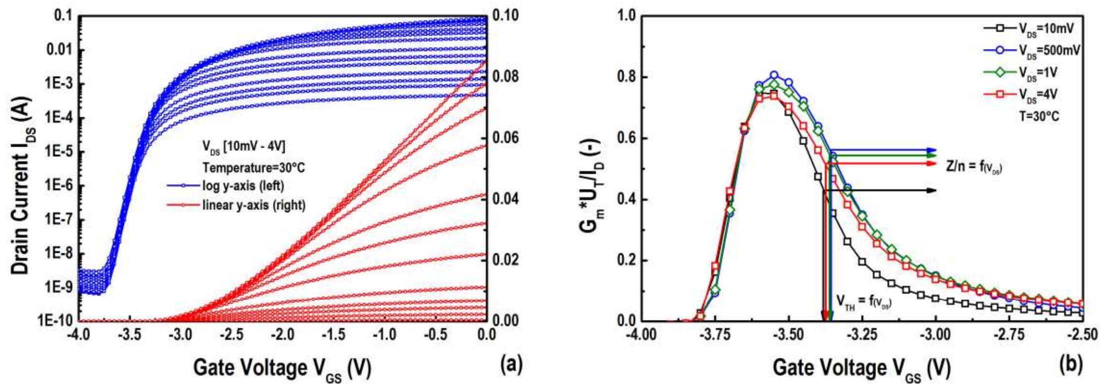

Fig. 1. **(a)** Family of DC transfer curves measured at T=30°C for Drain bias levels [10mV, 4V]. **(b)** Resulting transconductance efficiency curves for four Drain bias levels (10mV, 500mV, 1V and 4V) at 30°C, depicting V_{TH} extraction methodology described in [3] as applied in this work.

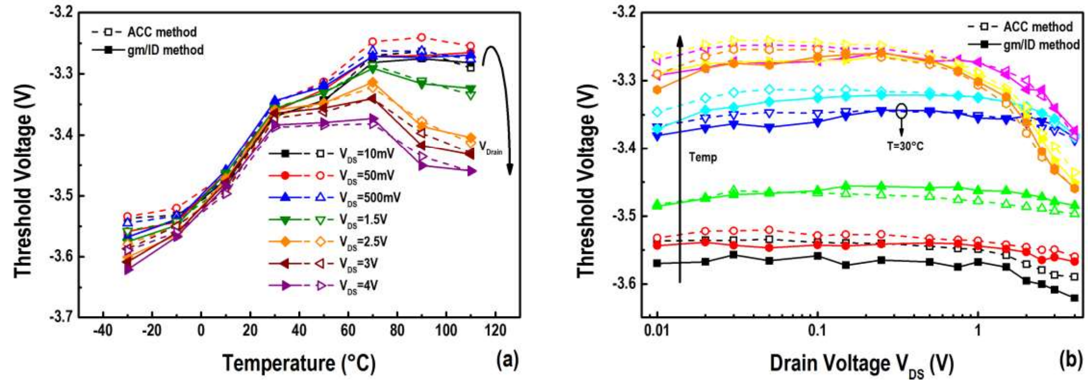

Fig. 2. Scaling of threshold voltage V_{TH} versus Temperature for the various Drain biases **(a)** and versus Drain bias for the whole temperature range measured **(b)**. Dashed lines and open markers correspond to the Adjusted Constant Current method [4], solid lines with filled markers to the Transconductance to Current Ratio method [3].

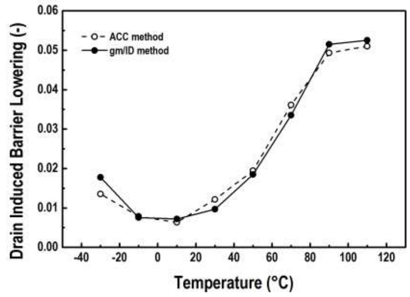

Fig. 3 DIBL factor as produced by the ACC method [4] versus the G_m/I_D method [3].

The similarity of the two methods can also be observed from the DIBL factor calculation ($n_{DIBL}=\Delta V_{TH}/\Delta V_{DS}$) shown in Fig.3, with both methods coming to an almost complete agreement. In summary, the present G_m/I_D method is observed to yield remarkably consistent results with the proven Adjusted Constant Current method, and they can thus be used interchangeably depending on available data and application scope.

[1] L. Chevas, N. Makris e.a., IEEE LAEDC, Puebla, Mexico, 2022. doi: 10.1109/LAEDC54796.2022.9908184.
[2] F. Jazaeri, J. -M. Sallese, IEEE Trans. Electron Devices, vol. 66, no. 3, pp. 1218-1229, March 2019, doi: 10.1109/TED.2019.2893302.
[3] M. Bucher, N. Makris e.a., IEEE LAEDC, Puebla, Mexico, 2023. doi: 10.1109/LAEDC58183.2023.10209129.
[4] A. Bazigos, M. Bucher, e.a. in IEEE Trans. Electron Devices, vol. 58, no. 11, pp. 3751-3758, Nov. 2011, doi: 10.1109/TED.2011.2164080.

This research has been co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T2EDK-00340).
This research has received funding from Horizon Europe research and innovation programme NANOMAT under the grant agreement No [101091433]